IMPROVE THE WELDING PARAMETERS FOR AISI 304L BY TIG WELDING

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ABSTRACT

AISI 304L steel is extensively used in structural steel because of its mechanical properties, withstanding for high temperature, compatibility with chemical and its weldability process. To join the thin thickness and medium thickness of stainless steel, TIG welding generally used for sound welding. The main interesting work of this work is to find the near optimal welding parameters with appropriate shielding gas in automatic TIG welding process for AISI 304L steel. The welding process parameters of the TIG welding process are the most important factors for affecting the sound of the weld, manufacturing rate and the economical of the welding joint. Welding current, voltage, welding speed and distance between nozzle to plate were optimized using RSM tool. The improved welding parameters with three different weld samples were prepared with three different shielding gases viz. 100% Argon, 98% Argon plus 2 % hydrogen and 95 % Argon and 5 % helium for studying the mechanical and metallurgical effect of the AISI 304L austenitic stainless.

KEYWORDS: AISI 304L, TIG Welding, RSM, Shielding Gas & Process Parameters

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1. INTRODUCTION

Joining practice of two similar or dissimilar metals permanently by using of pressure or heat or both is, welding. During joining the metal pieces by welding, the interfaces of the welding joint liquefied due to heat and solidified leads to permanent joint. Increasing the thickness of base metal more than 5 mm introduces the filler to form the weldpool, which creates the strong bond between similar and/or dissimilar material. Various factors are influence for the period of the welding procedure. Those factors decide the microstructure of the welded joint, and this microstructure decides the mechanical properties. As the result of these, hardness changes in welded joint due to sudden cooling, reaction of environmental oxygen with materials and formation of cracks in the welded joint (1-2).

The fabrication process of various pressure vessels, heat exchangers, nuclear grade components utilizes various grades of stainless steel materials in different shapes and sizes. The normal piece of austenitic tempered steel involves 18% Cr, 8% Ni compound, and furthermore it comprises Mo, Ti, Cu, and nitrogen. The common composition of austenitic stainless steel comprises 18% Cr, 8% Ni alloy, and also include alloys of Mo, Ti, Cu, and nitrogen. As the result of all these composition, it has excellent resistance against corrosion, increases the creep rupture strength and improves the impact strength. Recently, this austenitic stainless steels widely used in nuclear plant (3-4).

Because of wear and corrosion resistance of stainless steel, it is widely used for several engineering applications. They usually contain from 12-27% chromium and 1-2% manganese, with in some cases, the addition of nickel. The joining of various Stainless Steel (SS) materials requires different welding processes based on the system needs like thermal and structural properties. Tungsten Inert Gas welding (TIG) is one of the arc welding

processes, that tungsten electrode, which is non-consumable electrode to produce an arc to join the stainless steel materials to fabricate different structural components (4-6).

The major defects of the stainless steel are presence of cracks in welded zone and HAZ. These cracks are generally controlled by optimizing welding process variables on weld bead geometry (6-8).

Weld bead geometry of the welded joint shows a significant role for deciding the mechanical and microstructural characteristics of the stainless steel. TIG welding process strongly characterized the geometry of the weld bead.

The welding parameters such as welding current, welding voltage, torch speed, electrode vertex angle, arc-gap, shielding gas, etc. also will decide the metallurgical and mechanical characteristics of the joint. These welding parameters will influence the quality and production of the industries. (8-9)

In the conventional GTAW process while joining thin sections of plates, the operator can adjust the parameters during the welding process to get the sound welding. But in the automatic GTAW process, it is not possible to adjust the parameters during welding. This will leads to distortions, defects and imperfections found highly due to high heat input. So, it is important to optimized parameters before starting welding.

The trials revealed right now various parameters and to methodically examine the impact of shielding gas weld joint appearance, shape of the welded joint and ferrite substance of austenitic 304L steel GTAW welds. Several research works have been based on optimization of welding parameters based on a particular gas flow rate. But, the effect and quality of the welded joints varied depending upon the gas flow rate. This experimental study, not only discuss the optimization, also discuss the effect of three different gas flow rate.

2. EXPERIMENTAL SETUP

The stainless steel, AISI 304 L sample plates having the size of 250 x 125 x 3mm thickness, cut by Computerized Numerical Control (CNC) machine. The edges of sample plates were machined according to the standard gas tungsten arc welding joints at an angle of 90 degrees (butt joint) with the help of Universal milling machines. By using the mechanical clamps, the initial configuration of the sample pieces was achieved in proper position. Straight polarity DCEN used during for welding processes. 10 liter/min rate of shielding gas supplied during welding. 3 different types of gases namely 100% Argon, 98% Argon plus 2 % hydrogen and 95 % Argon and 5 % helium used for the optimum sample to know the mechanical and metallurgical studies. The chemical composition of AISI 304 L is given in table 1. It is welded with single pass by using Automatic TIG Welding. The welding torch moves with help of an electrical motor. There is no filler wire used for welding sample plates.

Table 1: Chemical composition of AISI 304L

Chemical element	C	Cr	Mn	Si	S	Ni	Fe
% wt	0.02	18	18	1	0.01	11	Bal

3. DESIGN PROCEDURE

3.1. Finding the Working Ranges of Welding Process

A few trail runs were conducted on the base metal to discover working sorts of TIG welding parameters. Combination of different welding process parameters was carried out for during the trail run. Increasing the welding current above 190 A, results the defect of spatter and undercut on the weld bead. Decreasing the current below 70 A shows the defect of less

penetration and inadequate fusion. Increasing the welding speed above 170 mm/min results in the defect of inadequate penetration and inadequate fusion. Decreasing the welding speed less than 130 mm/min, increases the heat input and undercut will be occurring. Increasing the nozzle to plate distance above 7 mm, results in the defect of spatter poor penetration, poor fusion and unstable arc.

Following condition is utilized to discover the working sorts of the welding parameters (10).

$$W_i = (2[2W - (W_{max} + W_{min})]) / (W_{max} - W_{min}) \quad (1)$$

Where, W_i is the required coded estimation of a parameter W . W is any estimation of the parameter from W_{min} to W_{max} ,

Table 2 gives the feasible range of welding process parameters and table 3 gives the different welding parameters which are current, voltage, welding speed and Nozzle plate distance for 30 weld coupons were welded by Automatic TIG welding machine. This design matrix was developed by CCD technique. All the experiments were conducted at NIT, Trichy. After the every experiment, the settings of all the parameters were changed and set the new parameters for the next experiment.

Table 2: Working Ranges of Welding Parameters

Parameter	Units	Levels				
		-2	-1	0	1	2
Welding current	A	30	70	110	150	190
Voltage	V	5.5	8	10.5	13	15.5
Welding speed	mm/min	110	130	150	170	190
Nozzle to plate distance	Mm	1	3	5	7	9

Table 3: Design Matrix

Run	A:Current	B:Voltage	C:Welding Speed	D:Nozzle to Plate Distance	Tensile Strength
	A	V	mm/min	Mm	MPa
1	110	10.5	150	5	637.26
2	70	8	130	3	270.874
3	70	8	170	3	175.156
4	150	13	170	3	441.87
5	110	10.5	150	9	495.78
6	190	10.5	150	5	530.87
7	110	10.5	150	5	635.345
8	110	10.5	150	5	630.45
9	30	10.5	150	5	250.87
10	110	10.5	110	5	450.87
11	110	15.5	150	5	513.45
12	110	5.5	150	5	385.34
13	70	8	170	7	288.485
14	110	10.5	190	5	340.45
15	70	8	130	7	325.45
16	70	13	170	3	267.87
17	150	13	130	7	521.487
18	70	13	170	3	266.78
19	70	13	130	3	375.845
20	150	8	170	7	504.78

Table 3 Contd.,					
21	150	8	130	3	506.45
22	130	10.5	150	1	350.65
23	110	10.5	150	5	634.865
24	150	13	170	5	523.45
25	110	10.5	150	7	600.78
26	150	13	130	3	513.198
27	150	8	170	7	508.97
28	150	8	130	3	506.89
29	110	10.5	150	1	360.654
30	70	13	170	3	259.681

Figure 1: Automatic TIG Welding Machine.

3.2 Development of Practical Relationship between the Parameters

The mathematical function of the output characterizes (11) using by this equation 2

$$Z = f(I, V, S, D) \quad (2)$$

Where Z is the response I - welding current; V - Welding Voltage; S – Welding Speed; D – Nozzle to plate distance.

The second order regression (polynomial) equation which represent the response of the surface can be represented by the following equation (3)

$$Y = \lambda_0 + \sum \lambda_i X_i + \sum \lambda_{ii} X_i^2 + \sum \lambda_{ij} X_i X_j \quad (3)$$

Considering the welding parameters, the chosen parameters could be expressed by the second order regression (polynomial) equation as (3)

$$Y = \lambda_0 + \lambda_1 I + \lambda_2 V + \lambda_3 S + \lambda_4 D + \lambda_{11} I^2 + \lambda_{22} V^2 + \lambda_{33} S^2 + \lambda_{44} D^2 + \lambda_{12} IV + \lambda_{13} IS + \lambda_{14} ID + \lambda_{23} VS + \lambda_{24} VD + \lambda_{34} SD \quad (4)$$

$$\text{Tensile strength} = 622.01 + 85.36A + 30.47B - 28.99C + 32.96D - 27.59AB + 11.76AC - 17.59AD - 5.47BC + 6.21BD + 14.29CD - 66.81A^2 - 43.45B^2 - 53.83C^2 - 48.86D^2 \quad (5)$$

4. RESULTS AND DISCUSSIONS

4.1. Radiography Test

The developed samples with Automatic GTAW, different shielding welds are subjected to radiography test for NDT evaluation. It is unavoidable to find defects free weld in samples even though highest care is taken during the preparation. In case of single pass automatic GTAW weld SS 304L samples; it was observed that concavity found in the root side, excess penetration during with filler wire and lack of penetration during autogenous welding.

The Radiography report has revealed clearly the indication of no concavity and found enough penetration. Figure.3. shows X-Ray images of weld coupon. Figure 3 (a) shows X-Ray images of weld coupon used 100% argon as a shielding and purging gas. Fig 3 (b) shows X-Ray images of weld coupon used 98% argon plus 2% hydrogen and figure 3(c) used 95%Argon plus 5%helium as a shielding and purging medium

The interaction of welding process parameters given in equation (5) summarized that, the tensile strength, not only influences by the influence of the welding parameters, but also influenced by the square of the each welding parameters.

Figure 2: X-Ray Images of Test Coupon.

4.2 Tensile Strength

Transverse tensile test specimens are machined from weld coupons (6 No's) as per ASME Sec IX. The tensile tests were carried out using a universal testing machine (13).

These tests were conducted as per ASTM E8-04 standards. Figure 2 shows the transverse tensile specimen as per ASTM E8-04 standards

Figure 3: Transverse Tensile Test Specimen.

The yield strength and tensile strength of the unwelded base metal are 233 Mpa and 539 Mpa, respectively. However, the tensile strength of the automatic GTAW weld joint, for 100% Argon and 98%Argon plus 2% hydrogen as a shielding gas are 635 Mpa and 570 Mpa, respectively. But in 95% Argon plus 5% helium the tensile strength is 498 Mpa only. So, when argon plus helium does not give enough tensile strength to the weld. Table 4 gives the tensile strength values for various shielding gasses. The hardness and distortion for 100% argon is more than 98% argon plus 2% hydrogen.

Table: 4 Tabulation of Tensile Values

Specimen	UTS (Mpa)	YS (Mpa)	% of Elongation	Location of Failure
100% Ar	635	294	56	HAZ
98% Ar+2% H ₂	570	281	33	HAZ
95% Ar+5% He	498	256	32	Weld

4.3 Bent Test

Root and face bend Test specimen machined to size of 200 x 20 x 3 mm thickness from both samples. These specimens were tested by bend testing machine, and after bending the specimens were subjected to LPT on specimen as shown in figure4. There were no significant defects found on bend test.

Figure 4: Bent Test for the Welded Specimens.

4.4 Micro Hardness Test

Figure 5 shows the micro hardness for those three welded samples, by using the 3 different shielding gases. At the point when Graph was firmly inspected, it recommended that the highest hardness value was obtained for Argon plus Helium and Argon plus hydrogen when without filler wire. Using the hydrogen shielding gas leads to high heat input due to more conductive to heat during the weld joint; results in reduction of hardness value. It is observed that it has uniform hardness

across the centre of weld and in the HAZ. But when in addition of filler wire, the highest hardness value was obtained for Argon

The maximum hardness was obtained from the base metal to HAZ transition zone in all the case. The predominant property of hydrogen & helium is their thermal conductivity, which is very less in case of Argon. This property has resulted in a marginal reduction of weld width when compared to pure argon shielding.

Figure 5: Comparison of Micro Hardness for 3 Different Shielding Gas.

4.5 Residual Stress

The residual stress pattern was studied on weld coupons before welding to have a comparison with base line data. The residual stress was measured to a distance of 35mm from the weld center of up to surface thickness of 10 μ m. Figure 6 shows residual stress of the three welded samples used three different shielding gases. It is observed that, Argon plus hydrogen combination shielding gas had better results when compared with Argon & Argon plus helium. The maximum residual stress reported for coupons are 314 Mpa (Ar), 253 Mpa (Ar+H₂) & 313 Mpa (Ar+He). The residual stress pattern was also uniform in the center of the weld with a slight peak in the HAZ for argon plus hydrogen in the welded samples

Figure 6: Comparison of Residual Stress for 3 Different Shielding Gas.

5. METALLURGICAL CHARACTERIZATIONS

The microstructure of SS304L steel grid comprises primarily of full austenite under the moderate cooling of balance solidification. However, during the non-equilibrium solidification process, quick cooling normally brought about the deficient change of ferrite phase to austenite phase. This may happen on the grounds that the change from ferrite phase to

austenite phase is a diffusion controlled procedure; the quick cooling in the welding procedure doesn't offer adequate time to finish the stage change after solidification and cooling to room temperature. Figure 7 (a) shows Microstructure images of weld coupon used 100% argon as a shielding and purging gas. Due to low thermal conductivity of Argon, slow cooling resulted in the transformation of ferrite phase to austenite phase, so it shows more ferrite phase.

Figure 7: (a) Microstructure Images of Test Coupon for 100% Argon.

Figure 7 (b) shows Microstructure images of weld coupon used 98% argon plus 2% hydrogen. The grains of the weld metal increased with increasing heat input, in addition of hydrogen shielding gas in protecting media. Weld metals exhibited a duplex structure consisting of delta-ferrite dendrites (dark) and equiaxed austenite.

Figure 7: (b) Microstructure Images of Test Coupon for 98% Argon + 2% Hydrogen.

Figure 7(c) used 95% Argon plus 5% helium as a shielding and purging medium. The grains of the weld metal became larger with increasing heat input, because of hydrogen addition in shielding media. Weld metals exhibited a duplex structure consisting of delta-ferrite dendrites (dark) and equiaxed austenite.

Figure 7: (c) Microstructure Images of Test Coupon for 95% Argon + 5% Helium.

6. ANOVA RESULTS

ANOVA is used to find the importance of the welding process parameters and the relationship between them. Table 5 gives Anova results. It is clear that, the developed relationship is adequate at 95% of confidence level. When values of 'prob > F' are less than 0.005, the relationship may consider as significant. In this case, I, V, S and D are the significant parameters. The relationship terms are not significant if greater than 0.1. How much the theoretical predicted values are closer to the actual values determined by the coefficient ' R^2 '. Table 5 which specifies that, high correlation occurs between the actual values and the predicted values. The ' R^2 ' value of this research work is 0.984, which shows the acceptable value with 'adj R^2 squared of 0.979. (14).

Figure 8: Normal Probability of Residual for Tensile Strength.

7. CONCLUSIONS

In this project work, detailed experiments conducted systematically to investigate the effect of shielding gas on weld morphology, angular distortion, and hardness when using the Automatic GTAW process to weld 3mm thick AISI304L stainless steel plates. Evaluations were done through NDT, DT and metallography tests. The primary results and conclusions are summarized as follows:

- Welding parameters with suitable shielding gas for welding of AISI 304L on the Automatic GTAW machine were optimized after carefully examining the mechanical properties, micro structural experimental studies and residual stress measurement
- Based on Transverse tensile test welding with Argon plus Helium does reaches UTS value in without filler wire
- Microstructure analysis reveals that the base metal is austenite. Dendrite formation found in weld metal. Transition zone or HAZ demonstrates obviously a growth of dendrite structure the grains of the weld metal became larger with increasing heat input, because of hydrogen addition in shielding media.
- Residual stresses measured in Argon plus hydrogen samples are comparatively low when compared with others shielding gas effect.
- It is observed that the argon plus hydrogen specimen has a uniform hardness across the centre of weld and in the HAZ in without filler wire welding
- It is observed that the argon plus hydrogen specimen has less delta ferrite by SEM Analysis and delta ferrite measurement in without filler wire weld.

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